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RESEARCH PAPER

Testing Biodegradable Seedling Containers as an Alternative for Polythene Tubes in Tropical Small-Scale Tree Nurseries

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Abstract Polythene tubes are the most commonly used seedling containers and their adoption can be attributed to high water retention that enhances seedling establishment as well as the desire for low-cost readily-available containers by nursery operators. Polythene tubes have drawbacks, however, because they adversely affect seedling root growth and are an environmental hazard. This study was conducted in Meru, Eastern Kenya, to investigate whether small-scale tree nursery operators are likely to adopt biodegradable seedling containers (cellulose papers and banana sheaths). It was hypothesised that biodegradable containers are better for seedling growth and are more environmental friendly than the widely used polythene bags. The study assessed the frequency of watering and growth (height and basal diameter) of *Calliandra calothyrsus* seedlings produced in various biodegradable containers under three conditions with varying watering requirements, i.e. light tree shade, shade net and polythene chambers, the first being widely used

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by farmers. The performance of these seedlings was later monitored in the field. Seedlings produced in biodegradable containers required more frequent watering than those in polythene bags under light tree shade and shade nets but less frequent in polythene chambers. Seedlings produced in polythene tubes had higher growth rates in the nursery, but when transplanted to the field, they were overtaken by those grown in the biodegradable containers due to transplanting shock after the polythene containers were removed. Biodegradable seedling containers can therefore be adopted in areas where water is not very limiting, and evaporation rates could be reduced and water-use efficiency improved by raising seedlings in simple polythene structures.

Keywords Biodegradable cellulose · Banana sheaths · Watering frequency · Shoot growth · Shade nets · Light tree shade · Polythene chambers

Introduction

Production and use of high quality seedlings is a critical consideration for successful tree farming and reforestation activities (Chunmei et al. 1994; Nicola 1998). In order to ensure that smallholder farmers have access to high quality tree seedlings in the tropics, establishment of low-resourced community nurseries is also necessary (Shanks and Carter 1994; Roshetko et al. 2010; Muriuki et al. 2012). Access to reliable water sources as well as affordable seedling containers have remained as major impediments to the success of such nurseries. To minimize the cost of production, farmers who operate small-scale tree nurseries use various locally available materials as seedling containers. These containers include household refuse such as small tins, milk packets, cardboard boxes, improvised banana sheaths, calabashes and clay pots (Mbora et al. 2008), as well as containers made from newspapers, corn starch, palm, cotton, paper, clay and cowdung (Anwar et al. 2002). Variation in the shapes, sizes and durability of these materials implies, however, that their use in nurseries cannot ensure high and uniform seedling quality.

To a large extent, the containers used to produce seedlings influence the quality of the seedlings and control the amount of water, air and mineral nutrients that are available for plant growth, the plant rooting system (Jaenicke 1999), and plant vigour (Campbell and Hawkins 2004). The volume (depth and diameter) of the seedling container further influences seedling quality and seedlings produced in larger containers are normally larger than those produced in smaller containers (Süleyman et al. 2010). Bigger tubes ensure that the seedling roots take longer to reach the sides or bottom and thus promote better root development (Muriuki et al. 2007). The 'best' container for a particular seedling crop depends on both biological and economic factors. Biological considerations include the size of the seedling or cutting, the ultimate size of the seedling at transplanting or sale, and the environmental conditions at the outplanting site (Landis 1990). Economically, the initial cost and availability of the container and the amount of available growing space in the nursery are primary considerations as well as the required amount of potting medium and seedling transportation costs.

Although several ways for categorizing tree seedling containers have been used, the most practical approach divides containers into two functional categories: those that are planted with the tree seedling (biodegradables), and those that are removed before the seedling is outplanted (Tinus and McDonald 1979). The latter category is the most common in the tropics, especially the use of polythene tubes (also commonly referred to as polytubes or polybags) with a closed bottom, to produce tree seedlings (Jaenicke 1999; Mohanan and Sharma 2005; Muriuki et al. 2007). Various projects encouraging adoption of agroforestry have promoted the use of polythene tubes and the materials have been adopted in many small scale nurseries as a result of the low cost of polythene. The polytubes are usually made of non-biodegradable polyethylene and have several drainage holes at the bottom. They are preferred especially during transplanting because they are easy to handle and transport thus reducing possible damage to the seedling roots.

Polytubes have various disadvantages. Their smooth sides restrict the growth and promote coiling of roots in the containers such that the roots are unable to anchor quickly into the ground after transplanting (Muriuki et al. 2007). Polythene tubes that are closed at the bottom cause roots that reach the bottom to coil around leading to root deformation which has adverse effects on tree growth and vigour (Cedamon et al. 2004). Polytubes are removed and dumped during out-planting yet they are non-biodegradable. Dumped polythene materials find their way into waterways and block sewerage systems thus contributing to floods and breeding areas for mosquitoes and other vectors (Sanghi 2008; Adane and Muleta 2011). Other detrimental results of polythene use include death of domestic and wild animals after ingesting the polythene, deterioration of the natural beauty of the environment and reduction of water percolation and proper aeration in the soil when dumped in agricultural fields. This last effect is particularly important because, after removal of seedlings, the tubes are destroyed and not reusable, so often tree planters bury the tubes in the soil to prevent them from being blown around.

The demerits of polythene bags have prompted governments to ban or impose levies and taxes on their use (UNEP 2005; Adane and Muleta 2011). These measures will make the materials either more costly (if taxes are raised), or unavailable to users (if banned). Alternative containers for tree seedlings need to be developed and tested, especially those that are biodegradable. While middle income people are more aware of environmental issues and sometimes pay more to invest in positive practices (Sanghi 2008), low income consumers are not likely to do so, especially if such positive practices increase their costs. Small-scale nursery operators are therefore not likely to invest in alternative seedling containers if such containers significantly raise production costs or reduce seedling quality.

The great merit with biodegradable pots is that, unlike polytubes, they do not have to be removed when seedlings are transplanted. Further, biodegradable pots promote better drainage and aeration which helps root growth. This reduces the risk of transplant shock (Gerlach 2007). When outplanted, there is little disruption to the growth vigour of the seedlings because the roots grow through the side wall of the pot into the soil thereby reducing the problem of root congestion caused by plastic pots. Because the pots lighten in colour as they dry out, one is also able to know exactly when to water the seedlings. The main disadvantage with biodegradable

pots is that they are fragile and require careful handling, especially when transporting seedlings. They also lack a solid wall with anti-spiraling features such that seedling roots grow randomly, often into adjacent containers. Another drawback is that they often become covered with algae and mold in the nursery and thus become difficult to handle (Landis 1990).

Water is essential to achieve the target seedling but lack of it is a major constraint to small-scale nursery operations. While nursery operators are advised to establish nurseries in sites with constant water supply, very frequent watering also increases labour costs. Seedling containers that increase the frequency of watering therefore have minimal chances of adoption unless they confer other benefits to tree planters. The potential for adoption of seedling containers by resource-constrained nursery operators is further reduced if the containers produce seedlings that grow sub-optimally. Recommendations to small-scale tree nursery operators on use of biodegradable seedling containers therefore need to include practices that can miminise seedling water requirements without compromising the physical quality of the plants. Seedling water requirement can be moderated through shading or establishment in propagation chambers that concentrate humidity within the chamber thus reducing evapotranspiration (Landis 1990; Jaenicke 1999).

This study sought to investigate the potential of biodegradable potting materials sourced from Ellegard AS, Denmark to be used as tree seedling containers by small scale nursery operators. The specific objectives were: (1) to compare the frequency of watering of seedlings produced in three container types under three conditions that reduce seedling watering requirement; (2) to compare the shoot growth rate (height and basal diameter) of seedlings grown in three container types in the nursery; and (3) to compare the rate of decomposition of the various biodegradable container materials and its effects on root status and plant growth rate when seedlings are planted in the field.

Experimental Site Characteristics

The experiment was carried out at a nursery managed by field staff of the World Agroforestry Centre (ICRAF), at Kaguru Agricultural Training Centre (ATC) in Meru County, Kenya, between June 2009 and December 2010. The site is located at latitude 0°05′S and longitude 37°40′E. The rainfall is bimodal with long rains usually starting at the end of March while the short rains start in October, although this climatic pattern has been fluctuating in recent times (see Fig. 1). Soils are of volcanic origin and generally fertile (Jaetzold et al. 2006). Meru is part of the central Kenya highlands where the main economic activity is smallholder farming and many farmers practice stall-fed dairy cattle and goats husbandry (Franzel et al. 2003; Maigua 2006).

Research Method

A randomized complete block design (RCBD) was applied in this experiment. Five seedling container types—polythene tubes, banana fibre rolls (herein referred to as

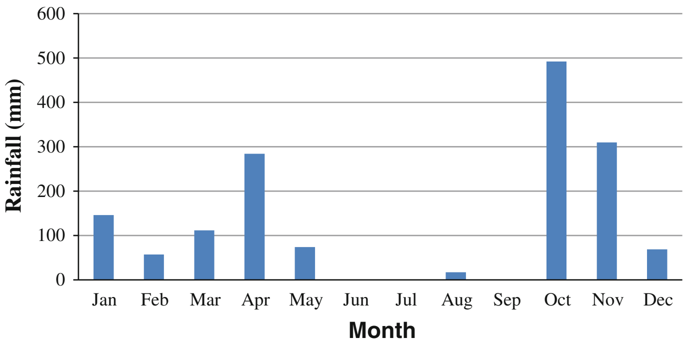

Fig. 1 Monthly rainfall at Kaguru Farmers Training Centre (Meru, Kenya) in 2009

Fig. 2 Improvised polythene chambers placed under shade nets to reduce moisture loss by seedlings raised in them

banana sheaths)—and three types of biodegradable cellulose paper—FP, VP and EP[1]—comprised the experimental factors with a set of 30 pots of each of the container types constituting an experimental unit. Three conditions that reduce seedling water requirement in the nursery comprised the blocks. These are light tree shade, 40 % shade net and fabricated polythene structures (chambers) placed under shade nets (illustrated in Fig. 2). *Calliandra calothyrsus* Meisn. was chosen for use in the experiment because it is an orthodox species and establishes easily in nurseries. Native to Central America, *C. calothyrsus* has become widely adopted as a popular exotic fodder and soil improvement species in Kenya (Orwa et al. 2010).

[1] The biodegradable materials EP, FP and VP are part of the Ellepot System produced by Ellegard A/S (company) of Denmark. Type EP and FP are papers with holes that are glued in such a way that the holes remain open. They consist of cellulose with polyester for enforcement. Type EP is designed to decompose in 8–12 months while type FP is lighter and is designed to decompose in 4–6 months. Type VP is polyester/viscose non-woven paper without holes that is expected to decompose in over 12 months.

The banana fibres and cellulose materials were cut into tubes measuring 4 in. × 6 in. (with a volume of about 400 cm^2) similar to the polythene tubes. The cutting was done carefully to ensure that the tube height was as uniform as possible for all the test materials because container height influences the rate of drainage of the water in the substrate (Landis 1990). The pots were filled with forest soil and randomly placed under the three conditions for reducing seedling water requirement (hereinafter referred to as watering reduction conditions). Three repetitions per experimental factor were randomly set under each of the three watering reduction conditions in order to minimize bias resulting from environmental conditions, especially due to orientation of the nursery beds in which experimental units were placed, in relation to the sun. This made a total of 1350 pots (30 pots × 5 container types × 3 repetitions × 3 watering reduction conditions). Two *C. calothyrsus* seeds were sown into each pot to ensure maximum germination and minimize need for transplanting germinated seedlings into empty pots. After germination one seedling was removed from any pot where both seeds had germinated.

Measurement of the watering frequency and seedling growth rate at the nursery was conducted for a period of 100 days from 16th June to 23rd September 2009. This period was selected because little rain was expected at the site (see Fig. 1 for actual rainfall at the site during the experiment year). However clear polythene sheets were placed above the seedlings established under the two shade types (light tree and shade net) whenever signs of rains were detected to prevent any unaccounted water input. Watering was done on a need basis for each experimental unit (set of 30 seedlings) whenever the technician observed that the substrate was drying and plants in the unit had lost turgidity. Every seedling in the units where drying was observed received 100 ml of water,[2] and every day that watering was done was recorded for each unit. The seedling height and basal diameter were measured monthly for the 12 seedlings inside each experimental unit. Basal stem diameter was measured at 1 cm above the substrate level using Vernier callipers while seedling height was measured from the substrate level to the tip of the youngest leaf using a metre rule.

In order to minimize differences in seedling sizes at transplanting time, a separate set of seedlings was raised in each of the five container types in the polythene chambers between February and May 2010 for field establishment. The seedlings were watered as frequently as necessary to ensure optimal growth for 3 months then hardened (out of the chambers) for 1 month. After hardening, they were planted in Kaguru ATC demonstration farm in plots of 21 seedlings (three rows of seven seedlings each) replicated in three blocks of the five experimantal factors (container types) in a RCBD design and measurements taken for 6 months (4th June to 5th December 2010). The seedlings raised in polythene bags were removed from the containers before planting while those raised in biodegradable materials (including banana sheaths) were planted in the containers. Immediately after outplanting,

[2] Watering tests conducted prior to the experiment showed the field capacity of the substrate was about 150 ml at first watering in the 4 in. × 6 in. polytube and the available water was about 80 ml at *C. calothyrsus* wilting point. It was therefore estimated that 100 ml of water would be sufficient per seedling to compensate for the lost water and correct for any lack of uniformity between the seedlings as the excess water would drain off.

Fig. 3 Roots of *C. calothyrsus* penetrating through a biodegradable seedling container 6 months after establishment in the field

the baseline seedling height and basal stem diameters were measured and recorded. The seedling sizes were thereafter measured monthly over the 6 months period using the same tools and approach as in the nursery.

Destructive sampling was carried out in every plot bi-monthly to assess the biodegradability of the seedling container and the extent of plant root restriction. At the first assessment, 2 months after planting, a plant was identified randomly in the first row of each plot of 21 plants, and the soil around the plant dug out carefully, ensuring not to tear the tube material (illustrated in Fig. 3). The degradation of the material was assessed by scoring how the roots of the plant had torn through the material. Scoring was done systematically for every fourth plant from the one randomly selected first. The scoring was a tri-scale as follows: 3. highly degraded (over 60 % of the material was shredded after roots had torn through); 2. moderately degraded (40–60 % of the material shredded); and 1. little or no degradation (<40 % of the material shredded). Three classes were also used to score plant root restriction by the potting material: 3. a little strained (<10 % of the roots had some straining or coiling around the container); 2. moderately strained (10–30 % of the roots had some coiling); and 1. highly strained (more than 30 % of the roots had some coiling). The assessed plants were re-planted after scoring but excluded from subsequent assessments and the plants next to them were scored in the following assessment.

The SPSS and GENSTAT packages were used for data analysis. Independent sample *t* tests and Analysis of Variance (ANOVA) were applied to test for differences between various experimental factors. Where *F* tests were significant, experimental factor means were compared on the basis of the least significant difference (LSD). A 5 % significance level was adopted.

Table 1 Average number of watering days for *C. calothrysus* seedlings raised in five container types under three watering reduction conditions through a 100 day growing period

Watering reduction condition/ container type	Light tree shade	Net shade	Polythene chambers	Container type average	SD	CV
EP paper	41_a	36_c	21_e	32.7_f	10.41	0.32
FP paper	39_a	37_c	22_e	32.7_f	9.29	0.28
VP paper	42_a	37_c	22_e	33.7_f	10.41	0.31
Polybags	32_b	28_d	25_e	28.3_g	3.51	0.12
Banana sheaths	41_a	40_c	26_e	35.7_f	8.39	0.24
LSD	5.263	5.241	4.874	5.143		
Watering reduction condition average	39_a	36_c	23_e	32.6_f	12.2	0.44

The table shows the average number of days of watering each experimental factor under each watering reduction condition so the frequency of watering reported in the text is derived from dividing 100 (total measurement period) with the number of days shown in the table

Means followed by the same letter in each column are not different at $p = 0.05$

LSD least significant difference, *SD* standard deviation, *CV* coefficient of variation

Results

Seedling Watering Frequency in the Nursery

As indicated in Table 1, watering frequency was dependent on both the container and the watering reduction condition. Generally seedlings established in the polythene chambers required less frequent watering than those placed under both tree shade and shade nets. Those established in banana sheaths required the most frequent watering under all three watering reduction conditions. The biodegradable paper pots required more frequent watering than polythene tubes under both tree and net shade but less frequent watering in the polythene chambers.

The frequency of seedling watering was influenced by the watering reduction condition they were established under ($p < 0.05$). Seedlings grown under light tree shade were watered most frequently (every 2.6 days on average; Table 1) compared to those under the shade net (2.8 days) while those in the polythene structures were the least frequently watered (4.3 days). Under the light tree shade, the average watering frequency for polytubes was the least at an average of every 3.1 days and differed ($p < 0.05$) from all other containers namely: banana sheaths and EP (2.4 days), VP (2.4 days), and FP (2.6 days). A similar observation was observed under the shade net, albeit more improved, in that the frequency of watering was slightly reduced for all container types compared to the tree shade. In the polythene structures, biodegradable EP (4.8 days), FP (4.5 days) and VP (4.5 days) were watered least frequently compared to polytubes (4.2 days) and banana sheaths (3.8 days).

Seedling Growth Rate in the Nursery

The seedlings produced in polytubes attained the highest growth rate in all watering reduction conditions (Fig. 4). The seedlings grown in banana sheaths were slower in

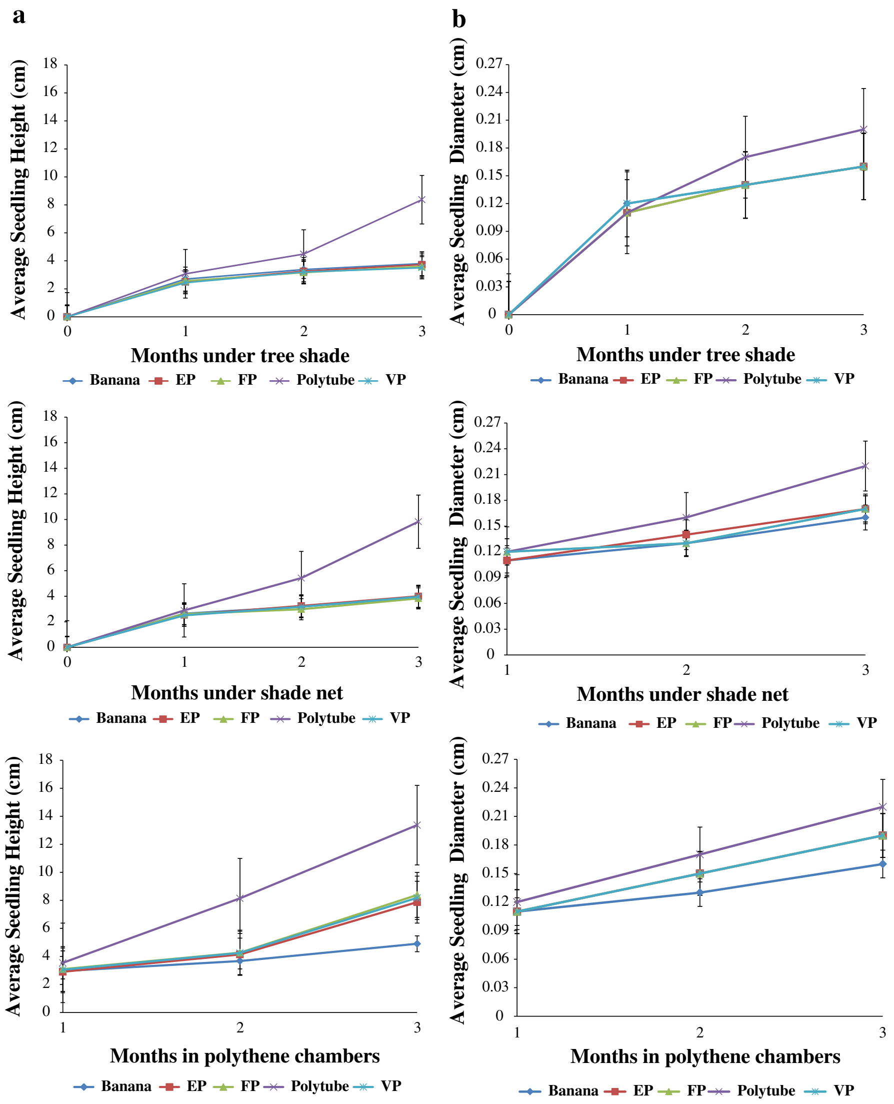

Fig. 4 Average rate of growth in height and basal diameter of *C. calothyrsus* seedlings planted in five container types under three conditions for watering reduction in the nursery

growth than those in biodegradable cellulose papers in the polythene chambers but not under the tree and net shade. The seedlings grown in the polythene chambers grew faster than those under the two shade types for all container types. There was no difference in seedling growth rate between the three types of biodegradable papers (EP, VP and FP) in all watering reduction conditions.

Influence by the type of container or watering reduction condition in which seedlings were raised was observed in seedling height but not basal diameter.

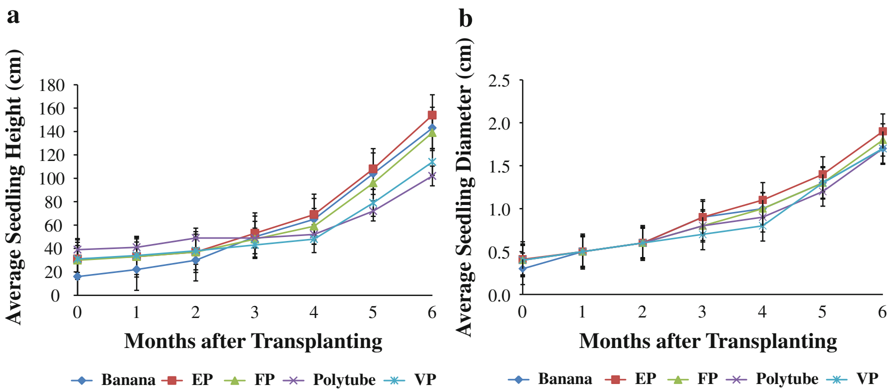

Fig. 5 Average field growth (Mean ± SE) in heights (*left*) and root collar diameter (*right*), of *C. calothyrsus* seedlings produced in five different containers

Seedling diameter means ranged from 0.16 cm (banana sheaths), through 0.17 cm (all three biodegradable papers) to 0.22 cm (polythene tubes) 3 months after sowing the seeds. Overall, the mean height of seedlings produced in polytubes was the highest under all watering reduction conditions (average 10.5 cm) and far greater than the heights of those grown in all three biodegradable papers (average 5.2 cm). The seedlings produced in banana sheaths had attained the least height at 4.2 cm. For the seedlings produced under the tree shade, the average height of those raised in polythene tubes was 8.4 cm, differing ($p < 0.05$) from other materials with a margin of 4.6 cm (banana sheaths), 4.7 cm (EP), 4.8 cm (FP) and 4.9 cm (VP). The pattern of height differences was not very different under the net shade from that under the tree shade. In the polythene chambers, the seedlings produced in polytubes and banana sheaths attained the highest (13.4 cm) and lowest (4.2 cm) heights respectively which differed with the seedlings grown in biodegradable papers at 7.9 cm (EP), 8.2 cm (FP) to 8.4 cm (VP).

Seedling Growth Rate in the Field After Out-Planting

At outplanting time, the seedlings produced in polythene tubes had attained the highest growth in height and diameter while those in banana sheaths had the least growth (Fig. 3). The seedlings grown in the biodegradable papers (EP, FP and VP) had similar growth characteristics. 1 month after transplanting, no differences were observed in mean diameters but height differences persisted in the same trend as at outplanting. The seedlings produced in polythene tubes attained a much higher mean height of 41 cm, biodegradable tubes had 33–34 cm height while seedlings in banana sheaths had attained the least mean height of 22 cm. Differences in the growth parameters (heights and diameter) became noticeable 2 months after outplanting when seedlings produced in banana sheaths and biodegradable papers EP and FP generally overtook seedlings produced in polytubes in size. Those produced in the VP paper grew at a slower rate than the other biodegradable materials but also overtook the ones produced in polytubes after 4 months (Fig. 5).

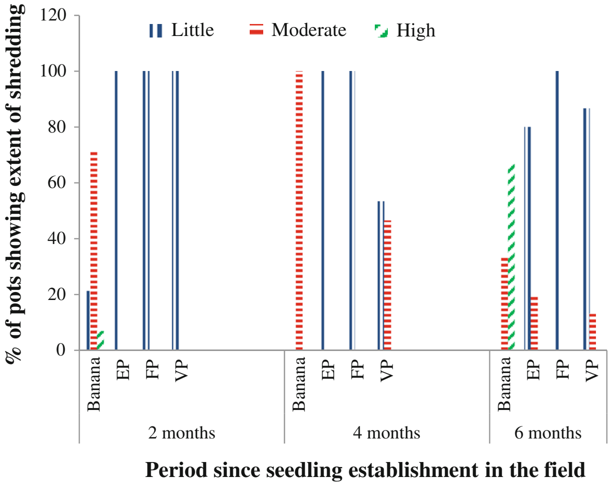

Fig. 6 Extent of pot decomposition at 2, 4 and 6 months after seedlings were established in the field in four types of containers

After 6 months of field establishment, growth differences were observed in mean heights while diameter measurements continued to show little differences ($p < 0.05$). The seedlings produced in polytubes had attained the least increment in both height (61 cm) and diameter (1.22 cm) while those produced in EP biodegradable paper had attained the highest diameter increment (1.49 cm). The highest height increment was attained by the seedlings produced in banana sheaths (127 cm) and at 143 cm average height, they differed little with EP which had attained the highest mean height (154 cm). Among the biodegradable papers VP had produced the least increment in both height (84 cm) and diameter (1.32 cm) after 6 months of growth in the field.

Rate of Container Degradation and Seedling Root Conditions After Transplanting

The biodegradable materials had not been extensively decomposed at the end of the monitoring, 6 months after establishing the seedlings in the field (Fig. 6). This included the FP cellulose paper that has been designed by the supplier to decompose in <6 months. The banana sheaths were however fairly decomposed with two-thirds of them being highly degraded at the third assessment (6 months). Bi-monthly assessment showed that the banana sheaths decomposed very fast after the fourth month and by the assessment of the sixth month, two-thirds of the assessed banana sheaths were almost fully decomposed (Fig. 6).

At 2 months of field establishment, the seedlings planted in the EP and FP biodegradable paper containers did not show straining of the roots to any great extent (Fig. 7). Two-thirds of those established in the VP pots and 86 % in banana sheaths showed some straining. For the seedlings scored in the second assessment,

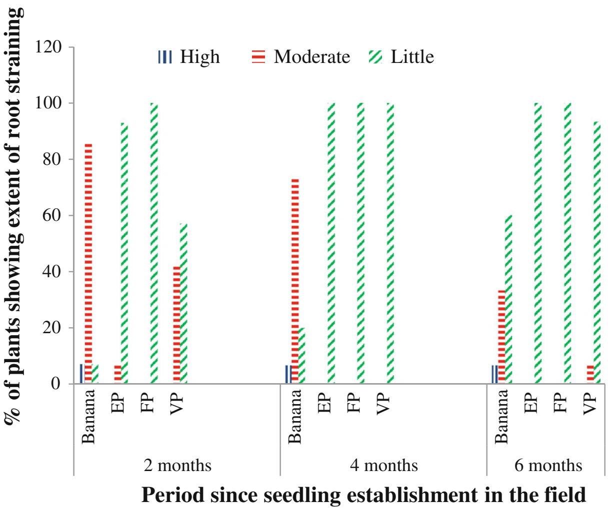

Fig. 7 Extent of seedling root straining at 2, 4 and 6 months after seedlings were established in the field in four types of containers

4 months after establishment, all biodegradable paper pots showed little root straining while three quarters of the seedlings in banana sheaths showed some root straining. After 6 months, only 7 % of the seedlings established in biodegradable VP paper, and 40 % of those in banana sheaths showed signs of root straining.

Discussion

Seedlings established in the biodegradable cellulose pots needed more frequent watering than those in polythene tubes when placed under light tree shade and the shade net. The seedlings raised under the shade net were however watered less frequently and had better growth rates, in all container types, than those established under the light tree shade (which is the common practice with small scale nursery operators). These results agree with those of Agyei-Dwarko and Ofori (2009) who observed reduction in watering requirements for oil palm seedlings when the shade was more intense. The gains observed by growing seedlings under the shade net compared to the tree shade (reduction in watering frequency and better seedling growth), do not seem to be so significant that nursery operators interested in adopting the biodegradable containers can also invest in the shade nets.

Watering frequency was reduced significantly for seedlings raised in biodegradable cellulose papers when the plants were placed in the polythene chambers. In chamber conditions, watering frequency for the plants in biodegradable papers was even less than for those grown in polythene tubes due to the increased humidity and possible capillary action. Therefore nursery operators can invest in improvised polythene structures to reduce the rate of watering plants produced in biodegradable cellulose containers. The observation however needs to be verified under real

greenhouse situations and/or when the polythene structures are placed under normal tree shade to come up with more concise recommendations. The costs of establishing these structures are likely to be higher than the increased costs of polythene tubes even if governments raised levies on polythene, especially considering that the structures are made of polythene and the levies will impact their costs too. There is need to investigate other biodegradable materials (such as biodegradable polymers) that could serve the same purpose as polythene sheets in covering such structures. A favourable policy measure to encourage adoption would be to consider including nursery operators who invest in such structures and biodegradable containers in payment for environmental services schemes.

Results indicate that banana sheaths require very frequent watering and stunt seedling growth in the nursery, even though these containers have been suggested as alternatives to polythene tubes because they are inexpensive and locally available on farms (Tengnas 1994; Muriuki et al. 2012). The stunting and more watering requirement makes them a less attractive alternative to seedling producers in addition to the labour required to prepare such sheaths. Seedlings raised in banana sheaths were also observed to be highly variable in appearance and yellowing of leaves was common. The implication is that tree nursery operators who use such containers would incur further losses as they need to cull and discard a lot of seedlings [as recommended by Jaenicke (1999)], thus increasing labour costs and leaving few seedlings for sale or outplanting. Banana sheaths can however be adopted by nursery groups that raise seedlings for members' use, if water is not limiting, and the group members share labour in preparing the sheaths as, in this study, the rolls produced very good field growth rates. This will particularly be attractive in banana growing areas as the materials would be readily available.

The studies by Bassman et al. (1989) and Mng'omba et al. (2011) showed that watering rate affected seedling growth more critically than watering frequency although the influence was species specific. Scagel et al. (2011) also showed that water stress can alter nitrogen uptake by plants. Biodegradable papers and banana sheaths must have drained substantial amounts of water (with nutrients) through the holes in their walls. Therefore, the amount of water and nutrients that was available to the seedlings after each watering event was lower in these containers than in polythene tubes and this could have contributed to the slow growth rates in the former. These findings are agree with study by Sakurai (2005), which showed that tomato seedlings raised in biodegradable pots developed shorter shoot and root lengths, fewer leaves, smaller leaf area, and showed a lighter dry weight, compared to seedlings raised in plastic pots. This situation of poor growth rates by seedlings could be worse when other tree species are raised in the nursery in the biodegradable pots. *C. calothyrsus*, the species used in this study, does not require a long nursery period compared to some tropical species that stay in the nursery for over 6 months. A lengthened nursery phase would lead to disintegration of the biodegradable containers causing more water to drain in every watering event and more nutrient leaching. There is therefore need to test how the biodegradable containers perform with other tree species.

The field growth rate was superior for seedlings raised in biodegradable materials (both banana sheaths and cellulose materials) than those raised in polythene bags.

Although the seedlings produced in polythene bags were bigger than those produced in the biodegradable materials at transplanting time, they suffered from transplanting shock due to removal of the containers, a situation that was avoided by the other seedlings. The cellulose papers gave room for the roots to access the substrate beyond their walls without strain, implying that delay in decomposition had little adverse effect on seedling establishment in the field. Banana sheaths had some initial effect on the roots and caused some visible strain in the first 4 months but the materials decomposed rather fast and the seedlings easily caught up with the others in growth, implying a vigorous establishment. Biodegradable materials thus gave a better chance for field establishment than polythene materials due to avoidance of transplanting shock. This is a good aspect of the biodegradable materials because seedling quality is ultimately manifested by ability to establish quickly in the field. However seedlings raised in biodegradable containers are also likely to suffer from transport shock in smallholder farmer field conditions which can reduce the gains observed in the study and this effect needs to be investigated further.

Seedlings raised in the VP material had slower field growth rates than the other two biodegradable paper materials including banana sheaths. This could have been as a result of the material (VP) lacking holes through which seedlings could easily penetrate container walls. Given that this lack of holes did not convey any advantage in the frequency of watering the seedlings in the nursery, this material seems to be the least appropriate to recommend for use by small-scale tree nursery operators.

Conclusion

Adoption of biodegradable seedling containers is desirable for environmentally friendly nursery production but small-scale nursery operators that suffer serious water constraints will find it difficult to use them unless they invest in simple polythene chambers. Even where water availability is not a major constraint, frequent watering will be needed if only shading (light tree shade and even shade nets) is used and this could raise labour costs. Coupled with the watering need, seedling growth rate is likely to be slower than that of seedlings produced in polythene tubes making them less attractive for customers. Availability of materials that are biodegradable to make structures that accumulate humidity and reduce the watering requirement would therefore be a good policy incentive in adopting biodegradable seedling containers. There is also need to conduct studies to establish whether the water lost from the container leaches out significant levels of nutrients, in which case, use of a rich substrate would be recommended to ensure that adequate nutrition is assured for the seedlings.

The study confirmed that transplanting shock when polytubes are removed from seedlings during out-planting lowered the rate of field establishment of seedlings making planting trees in biodegradable containers desirable. However this gain could be reversed if seedlings raised in biodegradable papers suffer transport shock in smallholder farmer field conditions and this effect needs further investigation. The study did not assess root development in the nursery for the seedlings raised in

the various materials and future studies need to address this issue in order to explain the faster field growth of seedlings raised in biodegradable materials especially the banana sheaths. The fast establishment rate in the field is however likely to attract tree growers to pay higher (premium) prices for seedlings raised in biodegradable materials when demonstrated to farmers and could raise the adoption of these materials in small-scale nurseries. However it is not appropriate to include the VP material in such promotion and/testing with farmers as results from this study showed it slowed plant growth in the field in addition to requiring more frequent watering in the nursery.

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